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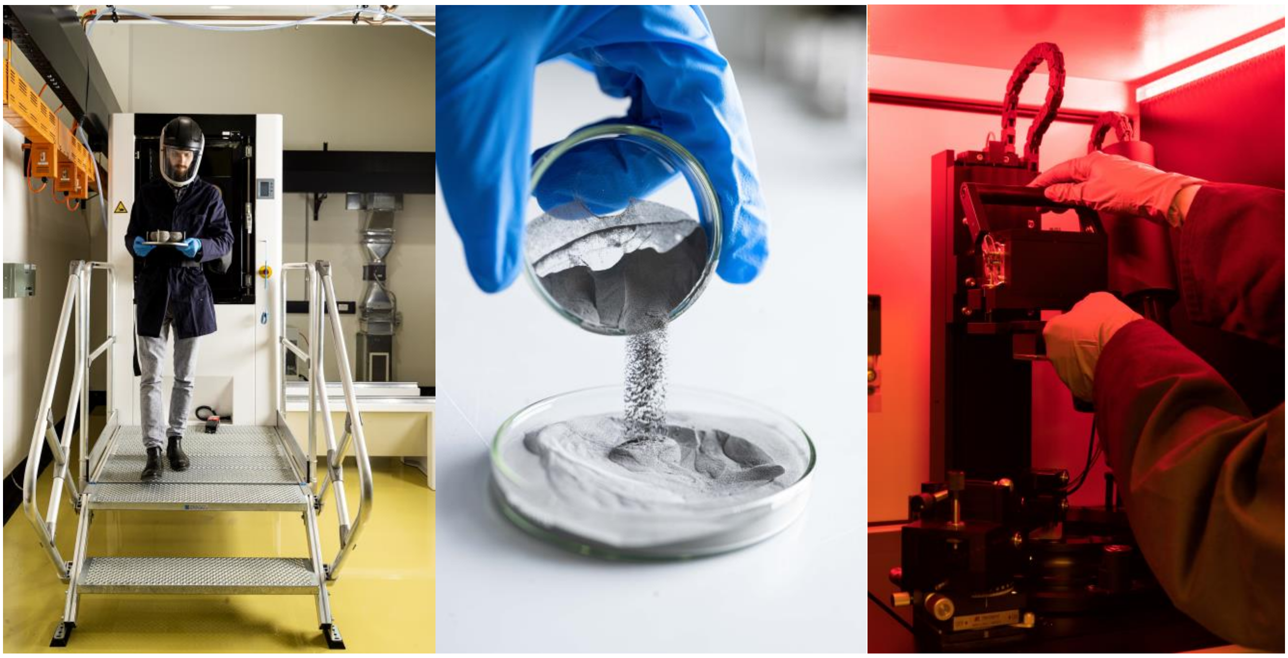
Sydney Manufacturing Hub

Materials Australia

Phase Transformational and Microstructural Evolution in Additive Manufacturing

9-10 August 2021



Symposium Organisers: Simon Ringer (Chair), Gwénaëlle Proust (Co-Chair)
Symposium Secretariat: Tanya Smith (Materials Australia), Renee Barber (University of Sydney)
Symposium Supporters: Sydney Manufacturing Hub, 3D Additive (AUSMURI), GE Additive

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Symposium Chair

Simon Ringer, Director, Core Research Facilities, Professor of Materials Science and Engineering, FIEAust, FRSN, FTSE, University of Sydney, Australia

Professor Simon Ringer is an engineer driving new research in atomic-scale materials design. He uses a materials science and engineering approach to learn how processes such as additive manufacturing can create special atomic structures in metals to deliver remarkable new properties. New ultra-strong lightweight alloys, materials with remarkable electrical conductivity or novel magnetic properties are his interest. Creating new materials via additive manufacturing is important for defence, aerospace, space, energy delivery systems as well as Australia's traditional extractive industries. He has worked in Sweden, Japan, the USA and Australia, holds patents in the design of materials, has published extensively and is a Fellow of the Australian Academy of Technological Sciences and Engineering. Professor Ringer works as the University of Sydney's Director of Core Research Facilities where he provides University-wide leadership of major research infrastructure strategy, planning and operations.

Symposium Co-Chair

Gwénaëlle Proust, Deputy Director, Sydney Manufacturing Hub, Associate Professor, School of Civil Engineering, University of Sydney, Australia

Gwénaëlle Proust' research aims at understanding the relationships between material properties and their microstructure and to improve material performance, ultimately leading to energy savings and to safer, more efficient devices. Her research projects encompass investigating and modelling manufacturing processes of materials and the effects of mechanical deformation on the microstructure evolution of metals, understanding the effects of complex loading on the mechanical response of materials and developing better performing composites by taking advantages of the individual properties of each component. The experimental aspect of her work is carried out using characterisation techniques such as optical microscopy, scanning electron microscopy and electron backscatter diffraction.

SYMPOSIUM SCHEDULE

DAY ONE – MONDAY 9 AUGUST 2021

11.30-11.45am	**Welcome and opening remarks** Gwénaëlle Proust (University of Sydney, Australia)
	Session Chair: Gwénaëlle Proust (University of Sydney, Australia)
11.45am-12.45pm	**Opening plenary** Tresa Pollock (UC Santa Barbara, USA) *At the Crossroads of Additive Manufacturing, Analytics and Advanced Materials*
12.45-2.00pm	**Lunch break**
	Session Chair: Andrew Breen (University of Sydney, Australia)
2.00-2.40pm	Behrang Poorganji (University of Toledo, USA) *Additive Manufacturing of Advanced Alloys: Material Design and Process Development Considerations*
2.40-3.20pm	Ma Qian (RMIT, Australia) *Simulation-Informed Laser Metal Powder Deposition of The Ti-6Al-4V Alloy for Better Microstructural Control*
3.20-4.00pm	Alexandra Shekhter (DST Group, Australia) *Air and Space Platforms Technologies: Outlook and Challenges for Defence*
4.00-4.30pm	Simon Ringer (University of Sydney, Australia) *An Overview of the Sydney Manufacturing Hub and Related Capabilities at Sydney*

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DAY TWO – TUESDAY 10 AUGUST 2021

8.55-9.00am	**Welcome** Gwénaëlle Proust (University of Sydney, Australia)
	Session Chair: Gwénaëlle Proust (University of Sydney, Australia)
9.00-10.00am	**Opening plenary** Sudarsanam Suresh Babu (University of Tennessee Knoxville, USA) *Role of Thermo-Mechanical-Chemical Transients on Liquid to Solid and Solid to Solid Phase Transformations during Additive Manufacturing*
10.00-10.40am	Amber Andreaco (GE Additive, USA) *Characterizing Additive Materials: Pedigree Driven Case Studies*
10.40-11.00am	**Morning break**
	Session Chair: Xiaozhou Liao (University of Sydney, Australia)
11.00-11.40am	Sri Lathabai (CSIRO, Australia) *Laser Powder Bed Fusion Additive Manufacturing of Self-Expanding Nitinol Stents*
11.40am-12.20pm	Matthew Dargusch (University of Queensland, Australia) *Case Studies Exploring the Relationships Between Design, Properties, Microstructure and Phase Transformations During Additive Manufacturing of Titanium and Titanium Matrix Composites*
12.20-1.00pm	Laichang Zhang (Edith Cowan University) *Enhanced Performance of Metallic Lattice Structures Fabricated by Additive Manufacturing*
1.00-2.00pm	**Lunch break**
	Session Chair: Anna Paradowska (ANSTO and University of Sydney, Australia)
2.00-2.30pm	Wen Hao Kan (Monash University, Australia) *Effects of In-Situ Rolling on the Microstructure and Mechanical Properties of Additively-Manufactured Ti-6Al-4V*
2.30-3.00pm	Xiaopeng Li (UNSW, Australia) *Additive Manufacturing of Aluminium: Alloy Design and Machine Learning Assisted Process Optimisation*
3.00-3.30pm	Fatemeh Azhari (University of Melbourne, Australia) *Predicting the Tensile Properties of Additively Manufactured Ti-6Al-4V using a Crystal Plasticity Finite Element Model*
3.30-4.00pm	**Afternoon break**

DAY TWO – TUESDAY 10 AUGUST 2021 continued

	Session Chair: Simon Ringer (University of Sydney, Australia)
4.00-4.40pm	Matteo Seita (Nanyang Technological University, Singapore) *Grain Boundary Engineering of Stainless Steel 316L via Laser Powder Bed Fusion*
4.40-5.20pm	Dierk Raabe (Max Planck Institute, Germany) *Microstructure- and Alloy-Design for Additive Manufacturing*
5.20-6.00pm	Catrin Mair Davies (Imperial College London, UK) *Residual Stress Prediction, Mitigation and Model Validation in Laser Powder Bed Fusion of 316H Stainless Steel*
6.00-6.10pm	**Closing remarks** Simon Ringer (University of Sydney, Australia)

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DAY ONE – MONDAY 9 AUGUST

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Opening plenary – At the Crossroads of Additive Manufacturing, Analytics and Advanced Materials

Additive manufacturing promises new pathways for integration of advanced alloys with complex structural component design. Achieving desired properties mandates control of structure and an improved understanding of the processes that occur at the individual melt pool scale and their superposition as melting occurs on a layer- by-layer basis. The data challenges with additive manufacturing and the corresponding 3D quantification of structure will be addressed. New insights on structure development gained from 3D datasets with chemical, structural and misorientation information will be discussed for structural alloys printed by electron beam and laser powder based processes. In large 3D datasets, the persistence of grains and the accumulation of large crystallographic misorientations during printing been studied as a function of scan strategy. The benefits of multimodal data for characterization of submicron features will be discussed. Finally, challenges in the design of alloys that are tailored to these unique processing paths will be discussed.

Tresa Pollock, University of California, Santa Barbara, USA

Tresa Pollock is the Alcoa Distinguished Professor of Materials and Associate Dean of Engineering at the University of California, Santa Barbara. Pollock's research focuses on the mechanical and environmental performance of materials in extreme environments, unique high temperature materials processing paths, ultrafast laser-material interactions, alloy design and 3-D materials characterization. Pollock graduated with a B.S. from Purdue University in 1984, and a PhD from MIT in 1989. She was employed at General Electric Aircraft Engines from 1989 to 1991, where she conducted research and development on high temperature alloys for aircraft turbine engines and co-developed the single crystal alloy René N6 (now in service). Pollock was a professor in the Department of Materials Science and Engineering at Carnegie Mellon University from 1991 to 1999 and the University of Michigan from 2000 - 2010. Professor Pollock was elected to the US National Academy of Engineering in 2005, the German Academy of Sciences Leopoldina in 2015, and is a DOD Vannevar Bush Fellow and Fellow of TMS and ASM International. She serves as Editor in Chief of the Metallurgical and Materials Transactions family of journals and was the 2005-2006 President of The Minerals, Metals and Materials Society.

Additive Manufacturing of Advanced Alloys: Material Design and Process Development Considerations

Additive manufacturing technologies are revolutionizing modern component design across many industries while leading to an evolution in materials science and engineering. Understanding and controlling the materials ecosystem in additive manufacturing is an essential factor for successful adoption especially in the processing of advanced alloys. The relationships among materials chemistry, powder characteristics, processes, and final part performance are key and crucial concepts in additive manufacturing technologies. A more comprehensive understanding of aspects such as powder characteristics, liquid- and solid-phase transformations, and the effects of repeated thermal cycling on metallurgical structure development will be required to effectively apply a design-for-additive approach. This presentation will provide a review and summary of the materials ecosystem for additive manufacturing powder bed fusion processes and summarize opportunities and challenges. Additive manufacturing of NiTi shape memory alloys as an example of advanced alloy processing will be presented. In addition, some fundamental considerations on alloy design as well as process development, control, and optimization will be discussed with the focus on materials design, powder characteristics control, and AM process parameters.

Behrang Poorganji, University of Toledo, USA

Dr Behrang Poorganji is a Research Professor at the University of Toledo MIME department and Director of Advanced Manufacturing at the Applied Research Engineering Institute. Dr Poorganji has more than 20 years of experience in metallic materials processing with 10 years of direct working experience in Additive Manufacturing. Behrang holds a PhD in metallurgy and materials processing from Tohoku University in Japan and MBA from California State University. Most Recently, Behrang served as VP of Advanced Technology at Beehive3D, Inc., and he was the former director of the Materials Technology organization at GE Additive. Behrang led engineering teams on AM materials design, AM process development, powders processes, AM materials behavior, and characterization. Behrang has extensive experience in different management and the lead technical positions in Japan, Canada, and the USA in aerospace, power management, and automotive industries.

Simulation-informed laser metal powder deposition of the Ti-6Al-4V alloy for better microstructural control

Understanding the thermal history of a metal part during additive manufacturing (AM) is essential for process design and microstructural control. This study details the thermal history for laser metal powder deposition (LMD) of the Ti-6Al-4V alloy (wt%) using the Directed Energy Deposition (DED) module in Simufact Welding. The simulation identified necessary LMD conditions for in-situ decomposition of α' -martensite in Ti-6Al- 4V with respect to the build height. On this basis, rectangular Ti-6Al-4V coupons were fabricated and systematic microstructural characterisation confirmed in-situ decomposition of α' into ultrafine α-β lamellae in the as-built samples. In addition, the approximate in-situ transition time from $\alpha' \rightarrow \alpha + \beta$ (lamellar) during the LMD process was determined to be 30–40 s, which is two orders of magnitude faster than conventional isothermal decomposition of α'. The underlying reasons were analysed and attributed to precursor (clusters) development within the α' -martensite laths as well as at the α' -lath boundaries due to being frequently and rapidly heated to temperatures well above the β transus, supported by recent literature. The as-built lamellar α-β Ti-6Al-4V achieved yield strength of 951 $\pm$ 10 MPa and tensile ductility of 8.18 $\pm$ 1.8%. A variety of other insights were obtained from this simulation-based experimental study including microstructural control for LMD of tall titanium alloy components through in-situ decomposition of α' -martensite.

Ma Qian, Royal Melbourne Institute of Technology (RMIT), Australia

Ma Qian currently holds a Distinguished Professor appointment with the Centre for Additive Manufacturing, School of Engineering at RMIT University, Melbourne, Australia. His research interests include:

(i) metal additive manufacturing,
(ii) powder metallurgy of light alloys,
(ii) solidification processing,
(iii) surface engineering for medical applications,
(iv) metallic biomaterials, and
(v) high entropy alloys.

With his team members and collaborators, he has published 262 peer-reviewed journal papers and 71 conference papers in these areas, which have attracted more than 12,000 Scopus citations.

Air and Space Platforms Technologies: Outlook and Challenges for Defence

The primary mission for the Aerospace Division of the Defence Science and Technology Group (DSTG) is to contribute to the transformation of Australia's air power through world-leading science and innovation by leveraging science and technology (S&T) to deliver game-changing warfighting capabilities for Australia. The Aerospace Platform Systems capability seeks to optimise the structural and propulsion system performance of ADF platforms in the Aerospace Domain. Its role is to deliver innovative science and technology solutions for current and future aerospace domain platforms to ensure safety, maximize operational capability and availability whilst minimising sustainment costs. The platforms include fixed- and rotary-wing aircraft operating in the challenging conditions offered by the Australian environment, unmanned aerial vehicles constructed of materials with poorly understood fatigue properties, as well as space and hypersonic vehicles operating in conditions of extreme thermal and physical stress. The unique challenges faced by the ADF in sustaining aerospace platforms include assuring sovereign capability and flexibility under demanding operational and physical environments with small fleets, limited industry support and constrained budgets.

This presentation will review some of the work on air and space platforms technologies undertaken at DSTG, including: innovative approaches to the assessment and prediction of aircraft structural integrity in support of current and future ADF platforms; provision of trusted impartial S&T advice and solutions across both operational and acquisition time horizons; the development of innovative data-driven approaches like virtual and augmented reality and automated systems to enable maintainers to ensure the ongoing structural integrity of ADF platforms efficiently and non-invasively; the development of certification methodologies for additively-manufactured structural and propulsion components; and research into development of resilient materials technologies for space applications.

Alexandra Shekhter, Defence Science and Technology Group (DSTG), Australia

Alex gained her PhD from Monash University in 2003. She worked in the Department of Materials Engineering at Monash University as a research fellow for two years working on the microstructure and properties of high-strength maraging steels. Since joining DSTG in November 2002, Alex has been involved in long-range research focussing on emerging materials technologies for airframes. She has also worked on the certification of new technologies for use on military aircraft and on technical risk assessments for novel materials and technologies for new platform acquisitions. She has led research programs designed to assess the performance of metallic materials and technologies in next-generation military aircraft. In her role as Group Leader for Aerospace Metallic Technologies, she concentrated on developing the certification methodology for additive manufacturing for metallic aerospace components, and also served as the lead for Defence's additive manufacturing policy development. In 2020 Alex was promoted to Research Leader, Aerospace Platform Systems. In that role she is responsible for leading around 70 scientists, engineers and technical staff to provide optimised structural and propulsion technologies for Defence. She is also a lead for the "Resilience" theme within Resilient Multimission STaR Shot, a major part of the *Defence Science & Technology Strategy 2030: More, Together*. Alex is a on the committee for the DSTG/RMIT Structures and Materials Research Program and Industry Committee and Adjunct Professor of Materials Science and Engineering at Monash University.

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DAY TWO – TUESDAY 10 AUGUST

Opening Plenary - Role of Thermo-Mechanical-Chemical Transients on Liquid to Solid and Solid to Solid Phase Transformations during Additive Manufacturing

Peripheral arterial disease (PAD), a progressive disease occurring due to plaque accumulation in the arteries that carry blood to the extremities and vital organs, affects approximately 10% of the world population. Endovascular stenting is used to treat PAD due to its minimally invasive nature, resulting in short recovery times. A stent is an ultra-fine wire mesh “scaffold” that is permanently implanted in the artery to keep it open. Self-expanding stents made from Nitinol, a Ni-Ti shape memory alloy that displays superelasticity, are used in the treatment of PAD as they can be compressed and placed into the artery where they will expand to a pre-set diameter without the aid of a balloon. Once deployed, they can accommodate the severe deformations the arteries experience during limb flexion. The current manufacturing practice for Nitinol stents involves laser cutting the mesh structure from seamless microtubes. The relatively narrow range of microtube diameters available, combined with tooling and setup requirements, limit the variety of stent geometries. Additive manufacturing, uninhibited by tooling constraints, offers the possibility to achieve new and novel patient-specific stent designs, resulting in better conformity to arteries and improved recovery times. CSIRO and the Medical Innovation Hub have developed a 3D printing technology based on laser powder bed fusion (LPBF) for patient-specific Nitinol stents. In this talk we will discuss aspects of LPBF process development and post-build treatments and present preliminary bench test results on the fabricated stents.

Sudarsanam Suresh Babu, University of Tennessee Knoxville, USA

Dr Sudarsanam Suresh Babu holds the UT/ORNL governor’s chair professor in advanced manufacturing at the University of Tennessee, Knoxville and serves in the Department of Mechanical, Aerospace and Biomedical engineering. Suresh has a joint professorship with the Department of materials science and Engineering (MSE). As a Governor's Chair, Suresh has a joint appointment within Energy Science and Technology Directorate and in the Manufacturing Sciences Directorate at the Oak Ridge National Laboratory (ORNL). Suresh leads basic and applied research in a wide range of additive and other advanced manufacturing processes including product design implications in collaboration with faculty and students at UT as well as with researchers at the Manufacturing Demonstration Facility (MDF) at ORNL. He is also the director of the Bredesen Center for Interdisciplinary Graduate Research and Education. In 2020, Suresh has been appointed as a member of the National Science Board by the President of United States of America. Suresh obtained his bachelor’s degree in metallurgical engineering from PSG College of Technology, Coimbatore, India, and his master’s degree in industrial metallurgy-materials joining from Indian Institute of Technology, Madras. He obtained his PhD in materials science and metallurgy from University of Cambridge, UK in 1992. He has held various engineering, researcher and faculty positions in India, Japan, and USA throughout his career, before joining UT.

Characterizing Additive Materials: Pedigree Driven Case Studies

Additive manufacturing has opened a world of opportunities when it comes to creating material in complex shapes. Even so, the fundamentals of physical metallurgy still apply and must be considered when it comes to selecting feedstock as well as the on and off-machine processing paths. This talk will discuss the importance of pedigree when examining additive materials, concluding with examples of how phase transformations, microstructural evolution, defects, and geometric factors drove decisions in characterizing and ultimately utilizing additive alloys in various applications.

Amber Andreaco, GE Additive, USA

Amber started her career in GE Aviation in 2005 as part of the Edison Engineering Development Program. In 2008, she joined the Materials Behavior organization, taking ownership of the mechanical characterization and analysis for additive materials, including the DMLM Co-Cr characterization in support of the LEAP fuel nozzle as well as follow on GE9X and Catalyst additive alloy programs. She helped define requirements for additive material qualification and certification as well as facilitated introduction new methods for evaluating additive materials. In 2017, Amber joined GE Additive as a Principal Engineer for Materials Behavior, leading several initiatives for additive material characterization, focusing on mechanical testing and analysis methods. She is passionate about the technology and is actively engaged with both internal and external customers to drive the rapid adoption of Additive. She currently leads the GE Additive Materials & Process team, focusing on laser and binder jet modalities. Amber holds a Bachelor of Science and Master of Science in Materials Science and Engineering from Carnegie Mellon University and The Ohio State University, respectively.

Laser Powder Bed Fusion Additive Manufacturing of Self-Expanding Nitinol Stents

Peripheral arterial disease (PAD), a progressive disease occurring due to plaque accumulation in the arteries that carry blood to the extremities and vital organs, affects approximately 10% of the world population. Endovascular stenting is used to treat PAD due to its minimally invasive nature, resulting in short recovery times. A stent is an ultra-fine wire mesh “scaffold” that is permanently implanted in the artery to keep it open. Self-expanding stents made from Nitinol, a Ni-Ti shape memory alloy that displays superelasticity, are used in the treatment of PAD as they can be compressed and placed into the artery where they will expand to a pre-set diameter without the aid of a balloon. Once deployed, they can accommodate the severe deformations the arteries experience during limb flexion. The current manufacturing practice for Nitinol stents involves laser cutting the mesh structure from seamless microtubes. The relatively narrow range of microtube diameters available, combined with tooling and setup requirements, limit the variety of stent geometries. Additive manufacturing, uninhibited by tooling constraints, offers the possibility to achieve new and novel patient-specific stent designs, resulting in better conformity to arteries and improved recovery times. CSIRO and the Medical Innovation Hub have developed a 3D printing technology based on laser powder bed fusion (LPBF) for patient-specific Nitinol stents. In this talk we will discuss aspects of LPBF process development and post-build treatments and present preliminary bench test results on the fabricated stents.

Sri Lathabai, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

Dr Sri Lathabai received a Bachelor of Technology in Metallurgy from IIT Madras, India, and Master of Science and PhD in Metallurgy and Materials Engineering from Lehigh University, USA. After a post-doctoral fellowship at NIST, USA, she joined CSIRO in 1990. At CSIRO, her research interests have spanned from the study of fatigue, fracture and tribology of engineering ceramics to the development of advanced welding and joining technologies. Since 2011, her focus has been on metal additive manufacturing processes and their application to alloys of aluminium, titanium and steels. Her particular interest is in the study of the relationships between process parameters and the resulting microstructures and their influence on structural and functional properties.

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Case Studies Exploring the Relationships Between Design, Properties, Microstructure and Phase Transformations During Additive Manufacturing of Titanium and Titanium Matrix Composites

Advanced manufacturing of Titanium alloys has been an important research area at the University of Queensland since 2006, with projects spanning defence, aerospace and medical implant applications. Since 2013 the majority of this work has focused on additive manufacturing technologies which provide opportunities for innovative component designs utilising the obvious advantages of Titanium alloys including excellent specific strength, corrosion resistance and biocompatibility. Additively manufactured Titanium matrix composites are a recent focus because of the potential to further tailor properties for challenging applications. This presentation will include a number of case studies of some recent additive manufacturing research undertaken at UQ involving the relationships between properties, design and microstructure of Titanium components. The case studies are part of a broader portfolio of work from research programs within the Defence Materials Technology Centre and the ARC Industry Transformation Research Hub for Advanced Manufacturing of Medical Devices.

Matthew Dargusch, University of Queensland, Australia

Matt Dargusch is a Professor in the School of Mechanical and Mining Engineering within the Faculty of Engineering, Architecture and Information Technology at the University of Queensland. He is currently the Chief Technology Officer of the Defence Materials Technology Centre (DMTC) and the Director of the ARC Industry Transformation Research Hub for Advanced Manufacturing of Medical Devices. Professor Dargusch has made significant international contributions to research in the field of advanced manufacturing and materials with a particular focus on titanium alloys. He has published in leading refereed journals with over 10,000 citations. He has extensive experience in mentoring and supervision having supervised 21 postgraduate research students to completion and supported both students and Early Career Researchers to successful careers in both industry and the research sector.

Enhanced Performance of Metallic Lattice Structures Fabricated by Additive Manufacturing

Lattice structures (Periodic cellular materials) are a type of architectures constructed by an array of spatial periodic unit cells with edges and faces. Although lattice structures exhibit a range of superior properties, such as low elastic modulus, high specific stiffness and strength, large surface area, a large number of internal pores, and relatively low-stress level, the manufacturing by traditional technologies and the optimization of properties of lattice structured are limited because of poor control over the morphological characteristics of the pore network. The recent advances in metal additive manufacturing (AM) technologies have enlarged the design and manufacturing possibilities for lattice structures, which provides lattice structures with promising solutions for a variety of applications. This work presents the recent progress of additive manufacturing and enhanced mechanical and catalytic performance of lattice structures. The selective laser melting (SLM) produced and electron beam melting (EBM)-produced beta-type biomedical titanium lattice structures, as potential load-bearing implants, demonstrate excellent mechanical properties in terms of high super-elasticity, low Young's modulus and high compression strength, high energy absorption and fatigue properties. In addition, SLM-produced porous Fe-based metallic glass composite has a superior overall catalytic ability with high reaction rate constant and low activation energy than other catalysts. The reported reusability and overall catalytic ability in SLM-produced porous Fe-based metallic glass matrix composite hold the promise to design new generation catalyst approaching practical application and high economic value.

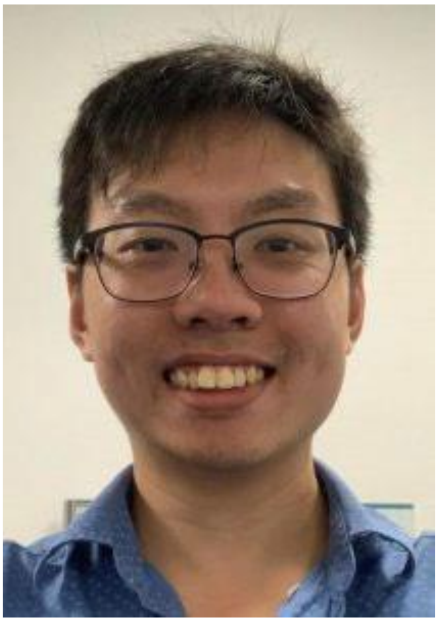
Laichang Zhang, Edith Cowan University, Australia

Laichang Zhang is a Professor of Materials Engineering and the Program Leader–Mechanical Engineering in the School of Engineering at Edith Cowan University (Perth, Australia). After awarded his PhD in Materials Science and Engineering at the Institute of Metal Research, Chinese Academy of Sciences, Professor Zhang held several positions at The University of Western Australia, University of Wollongong, IFW Dresden and Technische Universität Darmstadt. His research interests include metal additive manufacturing, light-weight alloys, nanocrystalline materials and metallic glasses as well as nanomaterials. He has published more than about 285 referred journal papers with an H-index of 63 and 12000+ citations and 24 ESI Highly Cited Papers, and he has delivered 19 plenary/keynote/invited presentations at international conferences. Several his findings have been covered by public media outlets, such as by live TV on ABC News channel and on CCTV-4 (China Central TV) and by many mainstream newspapers and magazines. He has supervised 13 PhDs and 2 Masters by Research to completion. In addition, he also serves as Editor or Editorial Board Members many journals, e.g. Advanced Engineering Materials, Scientific Reports, Metals, Frontiers in Materials, Materials Science and Technology, etc.

Effects of In-Situ Rolling on the Microstructure and Mechanical Properties of Additively-Manufactured Ti-6Al-4V

One of the main issues of direct energy deposition (DED), which is an additive manufacturing (AM) technique, is the growth of coarse columnar grains caused by heat transfer along the building direction. This results in highly anisotropic mechanical properties that can detrimentally affect the performance and qualification of DED-built components. To address this, a novel rolling device was built and integrated into a DED system so that mechanical rolling can be conducted in-situ as a component is being built. In this study, the integrated system was used to fabricate Ti-6Al-4V and its effects on microstructure and mechanical properties were investigated. Due to in-situ rolling, the prior-β grains that formed were equiaxed and also significantly refined. While the resulting α laths were also less textured, in-situ rolling was found to have a negligible effect on the α lath thickness. The yield and tensile strengths of the rolled alloy were not only found to be isotropic, but also improved as compared to the unrolled equivalent. In terms of ductility, in-situ rolling had a minimal effect on vertically-built samples but total elongation was significantly improved for horizontally-built samples. Lastly, a face-centred cubic (FCC, a = 0.43 nm) phase was observed between the α and β phases in all samples but was found to be coarser in the rolled samples. While the presence of an FCC phase has been reported several times in Ti alloys, the question of whether such a phase is an allotrope of Ti or simply a hydride remains highly controversial.

Dr Wen Hao Kan, Monash University, Australia



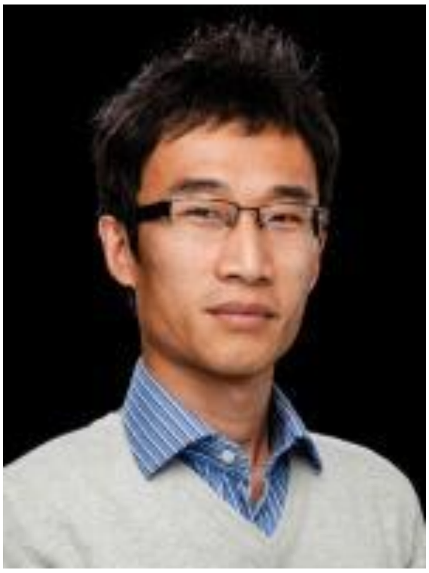
Dr Wen Hao Kan is a research fellow at Monash University's Monash Centre for Additive Manufacturing and is working on industrial projects that aim to build and deliver titanium aerospace components that have been re-designed to achieve substantial weight-savings through the design freedoms made possible with additive manufacturing. He is also leading various research projects in additively-manufactured stainless steels, aluminium alloys, titanium alloys and nickel superalloys with the aim of relating their microstructures to tensile, fatigue, toughness, corrosion and tribological properties.

Prior to working at Monash University, Dr Wen Hao Kan submitted his PhD thesis in 2017 and received his PhD award in 2018 for the development of ferrous metal matrix composites that are suitable for use in mining and mineral processing industries through a collaboration between the University of Sydney and Weir Minerals Australia Ltd. From 2017 to 2020, he was a post-doctoral research associate at the University of Sydney studying additively-manufactured aluminium and stainless-steel alloys, the recycling of industrial waste for the manufacturing of wear-resistant alloys, and the tribological behaviour of various engineering ceramics and polymers.

Additive Manufacturing of Aluminium: Alloy Design and Machine Learning Assisted Process Optimisation

Additive manufacturing, in particular laser powder bed fusion technique (LPBF), has been widely used to fabricate various aluminium alloys including Al-Si, 6061, 7075 alloys in the past decade with the aim to target applications concerning high strength and light-weighted structures. However, due to intrinsic materials characteristics, e.g., solidification cracking, not many aluminium alloys have satisfactory LPBF processability. Therefore, it is in urgent need to design and develop more suitable aluminium alloys and their composites for LPBF manufacturing. Meanwhile, once new aluminium alloys are designed, it is also of great importance to optimise the LPBF process to achieve high quality components without any apparent processing defects such as cracks or porosity. Moreover, how to achieve the desired mechanical properties in these aluminium alloys via manipulating the LPBF optimised parameters is another interesting and profound topic. In this presentation, a novel in-situ alloy design process was first introduced to develop nanoparticle decorated aluminium alloys for LPBF and the resultant microstructure along with mechanical properties were investigated. Following this, a machine-learning assisted LPBF process optimisation process for aluminium alloys is described in detail to provide new insights into the microstructure control and properties manipulation of LPBF fabricated aluminium alloys.

Xiaopeng Li, University of New South Wales (UNSW), Australia



Dr Xiaopeng Li is currently a Senior Lecturer and Australian Research Council DECRA Fellow in the School Mechanical and Manufacturing Engineering at UNSW Sydney, leading a research group working on additive manufacturing and advanced materials research. He is also currently a visiting scholar at Stanford University and EPFL. He received his PhD degree in Materials Engineering from The University of Queensland, Australia in 2013, where his PhD thesis won the Best Thesis Award by Australian Research Council Centre of Excellence for Design in Light Metals in 2013. After his PhD, he joined The University of Western Australia as an Assistant Professor, working on additive manufacturing of metallic glasses, light alloys and their composites till 2016. Following this, he joined one of the world-famous additive manufacturing groups led by Prof Jean-Pierre Kruth in KU Leuven, Belgium as a Research Fellow till 2017. In 2017, Dr Li was awarded a metal additive manufacturing machine from GE, US (worth of USD 350k and the only awardee outside US). In 2020, Dr Li is listed as World's Top 2% Scientists in Materials & Applied Physics & Enabling Strategic Technologies (single year in 2019) in the database of the most-cited scientists developed at Stanford University. His specific research interests include: development of various materials for additive manufacturing; design, simulation and machine learning for additive manufacturing; processing-microstructure-property relationship in additive manufacturing; hybrid additive manufacturing; and advanced materials and structures.

Predicting the Tensile Properties of Additively Manufactured Ti-6Al-4V using a Crystal Plasticity Finite Element Model

A multiscale finite element model integrating the microstructure with a crystal plasticity model including damage has been developed to predict the complete tensile stress-strain response of Ti-6Al-4V manufactured by selective laser melting. Two different image-based techniques were used to create a three-dimensional (3D) representative volume element (RVE) from electron backscatter diffraction (EBSD) images. The first method uses three orthogonal EBSD images to capture key 3D statistical information of the microstructure and creates a statistically equivalent microstructural RVE (SERVE). The second method reconstructs the physical 3D microstructure of the material from a series of parallel EBSD images obtained using serial-sectioning. Based on these 3D RVEs, the crystal plasticity finite element (CP-FE) model was then used to predict the complete tensile stress-strain response of the material, including damage post necking. Crack-band theory (CBT) was incorporated into the CP-FE model to accurately predict ductility and to minimize mesh size sensitivity. The accuracy of the stress-strain responses predicted using these RVEs was evaluated and the effects of each microstructure descriptor on the accuracy of the CP-FE simulation will be discussed. The new multiscale model provides a basis for a comprehensive Integrated Computational Materials Engineering (ICME) tool to enable the rational design of new high-performance materials.

Fatemeh Azhari, University of Melbourne, Australia

Dr Fatemeh Azhari is a postdoctoral research fellow at the University of Melbourne and the University of New South Wales. She works on a Next Generation Technology Fund (NGTF) project funded by the Defence Science and Technology (DST) group. She is currently working on developing an integrated computational materials modelling capability for Defence to fast-track materials innovation, qualification and integration. She completed a BSc degree in Civil Engineering at Isfahan University of Technology, Iran in 2010 and obtained her MSc degree in Structural Engineering from the same university in 2012. She worked as a Teaching/Research Assistant at George Washington University and National Crash Analysis Centre, US from 2013 to 2014. She obtained her PhD in Structural Engineering at Monash University in August 2018. In her PhD project, she worked on mechanical properties of ultra-high strength steel (Grade 1200) tubes under cooling phase of a fire. After completion of her PhD, she worked as a Research Fellow at Monash University for 10 months and focused on phase-field fracture/damage modelling of brittle and quasi-brittle materials.

Grain Boundary Engineering of Stainless Steel 316L via Laser Powder Bed Fusion

Grain boundary engineering (GBE) encompasses different material processing strategies that allow controlling the character distribution of the internal interfaces in polycrystalline solids, which are referred to as grain boundaries (GBs). In metals and metal alloys, GBE results in markedly improved GB-controlled properties, including strength, ductility, as well as resistance to fatigue and corrosion. Because of the copious mechanical deformation involved in GBE, this strategy finds limited application to parts produced using near-net-shape manufacturing processes, including additive manufacturing (AM).

In this study, we explore an alternative route to GBE of as-built AM alloys which requires no mechanical deformation. We leverage the large residual strain imparted by laser powder bed fusion processing (LPBF) of stainless steel 316L (SS316L) to trigger recrystallisation upon heat treatment. The recrystallized alloy exhibits a GB character distribution that is similar to that of materials processed by conventional GBE strategies. Interestingly, we find that the propensity of SS316L to recrystallize depends on the solidification microstructure—including the cell size and the amount of solute that segregates at their interfaces—which may be controlled by tuning the LPBF process parameters.

Our results open the path to producing AM-GBE alloys with improved performance which require minimal follow-on processing. They also indicate the possibility of integrating different GB character distributions within the same build by tuning the solidification microstructure site-specifically. These new materials showcase the opportunity offered by AM to design superior materials with controlled microstructure.

Matteo Seita, Nanyang Technological University (NTU), Singapore

Dr Seita is an Assistant Professor of Mechanical and Aerospace Engineering at NTU, where he leads the Additive Microstructure Engineering Laboratory (AddME Lab). The focus of the AddME Lab is on understanding and controlling the microstructure complexity brought about by additive manufacturing processes to design more sustainable metallic materials with improved reliability and performance. Owing to the multidisciplinary nature of his research, Dr Seita holds secondary appointments in the School of Materials Science and Engineering and in the Asian School of the Environment. In the latter, he brings his expertise on materials degradation in harsh environments, which he developed during his postdoc in the Department of Materials Science and Engineering at MIT. He earned his PhD in Materials Science from ETH Zurich in 2012, where he worked on gaining control over the microstructure of thin metal films by means of ion irradiation. In January 2018, Dr Seita was awarded the prestigious NRF Fellowship—a S$3M individual grant for early-career scientists—to develop novel additive manufacturing strategies for microstructure control of metal alloys.

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Microstructure- and Alloy-Design for Additive Manufacturing Steel

Additive Manufacturing is capable of producing highly complex parts directly from a computer file and raw material powders. Its disruptive potential lies in its ability to manufacture customised products with individualisation, complexity and weight reduction for free.

This presentation provides a brief overview of our research which aims to understand the impact of this manufacturing process on the micro- and nanostructures of the employed alloys as well as to develop metallic materials suitable for and exploiting the unique characteristics of Additive Manufacturing.

While Additive Manufacturing, and in particular Laser Additive Manufacturing, is by now fairly well-established as a process to produce metallic parts, studies targeting the microstructure-optimisation of existing alloys and the design of novel advanced alloys tailored specifically to Laser Additive Manufacturing are still sparse. The established alloys currently in use do not exploit the enormous opportunities inherent in this technique at all, leaving a gap towards its further development.

Dierk Raabe, Max Planck Institute, Germany

Dierk Raabe studied music, metallurgy and metal physics. After his doctorate 1992 and habilitation 1997 at RWTH Aachen he worked at Carnegie Mellon University (Pittsburgh) and at the National High Magnet Field Lab (Tallahassee) and joined Max Planck Society as a director in 1999. His interests are in physical metallurgy, aluminium alloys, steels, sustainable metallurgy, additive manufacturing, hydrogen, alloy design, computational materials science and atom probe tomography. He received the Heisenberg Award, the Leibniz Award and an ERC Advanced Grant.

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Residual Stress Prediction, Mitigation and Model Validation in Laser Powder Bed Fusion of 316H Stainless Steel

The laser powder bed process results in yield magnitude residual stresses at the parts surface which can be detrimental to the parts integrity, especially if combined with build defects or stress raising design features. Measuring, predicting and alleviating residual stresses are therefore important for component integrity assessments. Neutron diffraction and X-ray measurements have been performed on a range of specimen geometries. Finite element models have been developed to predict their residual stress distributions and subsequent relaxation using heat treatment and laser shock peening techniques. The influence of build orientation on residual stress distributions will be discussed and the effectiveness of residual stress mitigation techniques and predictive models examined.

Catrin Mair Davies, Imperial College London, UK

Dr Catrin Mair Davies is a Reader in Structural Integrity of Alloys in the Department of Mechanical Engineering, Imperial College London. She leads the EDF Energy High Temperature Centre at Imperial and has published over 80 Journal publications relating to experimental testing and finite element modelling of creep deformation, damage, creep crack initiation and growth, low-cycle fatigue, weld simulations, prediction and measurement of residual stresses, and the development of high temperature plant component condition monitoring tools for lifetime assessment. Her research has been used in the development of Industrial high temperature component assessment codes (R5, BS7010) and International creep crack growth and fracture toughness testing standards (ASTM E1457 and E1820).